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ORIGINAL ARTICLE

Dietary Boron Intake in the United States: CSFII 1994–1996

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We have developed a Boron Nutrient Database and estimated dietary boron intake using the Continuing Survey of Food Intakes by Individuals (CSFII) 1994–1996. Boron intakes were calculated for each CSFII 1994–1996 respondent who completed two 24-h dietary recall interviews ($n = 15\ 267$). Means, percentiles, and associated standard errors of usual intake were estimated using statistical methods of Nusser *et al.* (1996). Mean boron intakes for school-age children and adolescents ranged from 0.80 ± 0.01 mg/d (S.E.) for 4–8-year olds to 1.02 ± 0.04 mg/d for males aged 14–18. For female and male adults, the mean intakes were 1.00 ± 0.01 and 1.28 ± 0.02 mg/d, respectively. The 5th and 95th percentiles were 0.43 and 1.29 mg/d for 4–8-year olds, 0.47 and 1.79 mg/d for males aged 14–18, 0.41 and 1.87 mg/d for adult females and 0.53 and 2.40 mg/d for adult males. Food groups contributing the most to boron intake of respondents age 4 and older were fruits (25.1% of boron intake), beverages (19.5%), vegetables (18.1%) and grains (14.1%). These boron intake estimates from a U.S. representative sample are within the range of previous estimates. Boron intake was calculated for each person at the individual food level, enabling more detailed analyses of intakes and food sources.

Key Words: boron; nutrient intakes; trace minerals; U.S. population; CSFII.

INTRODUCTION

The Institute of Medicine's (IOM) Panel on Micronutrients was established under the Food and Nutrition Board's (FNB) Standing Committee on the Scientific Evaluation of Dietary Reference Intakes (DRI) for the purpose of reviewing the scientific literature on dietary micronutrients. This included potentially beneficial trace elements, such as boron, to assess the roles that they may play in health and to develop estimates of dietary intake that are compatible with good nutrition throughout the life span (FNB, 2000b). The purpose of the current research was to provide the FNB with the most accurate currently available estimates of usual boron

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daily intake, using data from the USDA Continuing Survey of Food Intakes by Individuals (CSFII) 1994–1996.

The Panel on Micronutrients of the IOM/FNB used these dietary intakes in their recent assessment of boron (FNB, 2001). The FNB did not establish adequate intake (AI) levels for boron because measurable biological responses of human subjects to variations in boron dietary intake have not yet been demonstrated. However, they found that there is evidence that boron has a beneficial role in physiological processes in some species. Studies in both epidemiology and human clinical trials can use these boron dietary intakes as a research tool to plan future studies and relate research results to U.S. human populations.

Many experiments performed with animals since 1981 have shown that boron deprivation affects the composition or function of several organ systems, including the brain and skeleton. Boron has also been demonstrated to affect biochemical indexes associated with the metabolism of numerous other nutrients, including calcium, copper, nitrogen, and cholecalciferol (Hunt, 1996; Hunt and Stoecker, 1996; Nielsen, 1996). However, the animals' responses to the intake of low dietary boron in most of these studies were enhanced when the animal was exposed simultaneously to nutritional stressors, such as deficiencies in calcium, cholecalciferol, magnesium, or potassium. Thus, boron appears to positively affect both calcium and magnesium metabolism and may be required for energy substrate utilization and membrane function (Hunt, 1996; Nielsen, 1996). Boron deficiency symptoms have also been reported in experiments on rats and chickens (Hunt, 1996) and have even been suggested in three clinical studies of human beings (Nielsen, 1996; Hunt *et al.*, 1997). A Joint FAO/IAEA/WHO Expert Consultation on Trace Elements in Human Nutrition recently declared that boron is "probably essential" (WHO, 1996). Recent evidence also suggests that boron is essential for early life stage development in *Xenopus* frogs (Fort *et al.*, 1999) and zebrafish (Rowe *et al.*, 1998), and boron deficiency resulted in cone photoreceptor dystrophy in the retinas of adult zebrafish (Eckhert and Rowe, 1999).

The goal of this paper is to provide current data on boron intakes of apparently healthy individuals. Data on dietary boron intake by human beings are fairly sparse. Boron is not included in the U.S. Department of Agriculture (USDA) nutrient databases (Perloff *et al.*, 1990; USDA, 1999), and no comprehensive analytical database exists on the boron content of specific foods. Most previous estimates of average boron intake, summarized as ranging from 1 to 2 mg/d for adults (WHO, 1996), are based on a limited number of foods and population segments. Our analysis of the previous CSFII (1989–1991) showed that U.S. boron intakes were slightly lower than had been previously estimated. The 5th percentile, median, mean, and 95th percentile boron intakes, respectively, were 0.43, 1.02, 1.17 and 2.42 mg/d for men and 0.33, 0.83, 0.96 and 1.94 mg/d for women (Rainey *et al.*, 1999b).

The purposes of this study were: to update and expand the Boron Nutrient Database (BNDB, version 1.0 to 2.0); estimate dietary boron intake from the CSFII 1994–1996 data using a statistical approach that estimates usual intake based on a limited number of days of consumption data; determine major sources of boron in the diet; and examine boron contributions from food groups.

MATERIALS AND METHODS

Creating Version 2.0 of the Boron Nutrient Database

Methods for developing nutrient databases have been previously published (Holden *et al.*, 1987; Schubert *et al.*, 1987; Lurie *et al.*, 1989; Haytowitz, 1989; Murphy *et al.*, 1991; Rand *et al.*, 1991; Mangels *et al.*, 1993), including those used to create the previous version of the BNDB (Ver. 1.0) (Rainey *et al.*, 1999b). In general, the same methods were used to develop the current version 2.0. This involved searching the literature for analytical boron concentrations in foods and calculating boron concentrations of other foods from the analytical data.

Analytical boron data from literature. A comprehensive literature search was conducted to assemble existing analytical boron concentrations of foods for the version 2.0 database. The boron concentrations found in recent literature and those in BNDB version 1.0 were evaluated for possible inclusion in version 2.0. The boron analytical data were reviewed using the critiquing methods developed by Holden *et al.* (1987), which rated data quality according to five major determinants: analytical method, analytical quality control, number of samples, sample handling, and sampling plan. These methods were modified to accommodate boron data evaluation.

As with version 1.0, conversion factors were applied so that all boron concentrations would be uniformly expressed as µg boron per 100 g of food or beverage. Data reported on a dry-weight basis were converted to wet weight using actual moisture levels or typical levels from USDA nutrient data. Data reported as boric acid were converted to elemental boron (H_3BO_3 is 17.5% boron by weight). Data reported as "below detection limits" were flagged as such and assigned a value that was half the stated detection limit for the analytical method (e.g., <2 µg boron per 100 g was assigned a value of 1 µg boron per 100 g). Flagging the data that were below detection limits enabled us to give precedence to lower detection limits when comparing multiple data points for a single food.

The analytical procedure described by each literature data source was systematically evaluated. A confidence rating (0, 1, 2, or 3) was assigned to each source based on critical steps that documented the boron concentration. Higher ratings were given where the documentation related sample origin; sample handling, processing, and subsampling to minimize contamination and loss; analytical quality control (i.e., use of blanks, control and reference materials, and control charts); replicate analyses; and error discussion.

Boron data accepted for inclusion in the database were determined by a variety of analytical methods: neutron capture prompt γ-ray activation analysis (PGAA), neutron activation-mass spectrometry (NA-MS), inductively coupled plasma-atomic emission spectrometry (ICP-AES), inductively coupled argon plasma-emission spectrometry (ICAP-ES), inductively coupled plasma-mass spectrometry (ICP-MS), colorimetry (readings at 640 µm), spectrophotometry (readings at 625 nm), and polarography. The use of multiple methods for a determination gave added confidence in the data by reducing the possibility of instrumental bias. Description of the specific analytical instrument and calibration method used in the food analyses should have been presented in detail for the highest data rating.

After analytical data were selected for inclusion, the database consisted of 1238 analytical boron concentrations from 20 literature sources. Five hundred and forty-one of the data points were of U.S. origin (Clarke *et al.*, 1987; Hunt *et al.*, 1991; Hunt and Meacham, 2001; Anderson *et al.*, 1994), including 234 foods analyzed in the U.S. FDA Total Diet Study (Anderson *et al.*, 1994) and recent analyses of 234 equivalent foods (Hunt and Meacham, 2001). Three hundred and fifteen boron concentrations were of Finnish origin (Nuurtamo *et al.*, 1980a, b; Varo *et al.*, 1980a–d) and 270 were from the United Kingdom (MAFF, 1998a, b). The remaining 112 boron concentrations were of foods from various sources in Japan (Ogawa *et al.*, 1979; Inoue *et al.*, 1980), Italy (Bionda, 1957; Minoia *et al.*, 1994), Saudi Arabia (Al-Warthan, 1993), China (Lu *et al.*, 1994), and Germany (Souci *et al.*, 1994).

We then determined the median for each food with multiple data points and used that value as the final boron concentration. This resulted in a total of 472 foods in the analytical boron database. These data were then used to calculate the boron content of additional foods.

Assignment of boron values to additional foods. From the 472 foods in the updated analytical database, boron was calculated for additional foods using basically the same methods used for version 1.0 of the BNDB (Rainey *et al.*, 1999b). This included calculations based on proximate differences (e.g., moisture, protein, carbohydrate, and/or fat) between foods with known boron concentrations and variations of those foods for which boron concentrations were needed. Examples include raw versus cooked, sweetened versus unsweetened, and dry versus diluted. Recipes were also used to calculate boron for many multi-component foods.

The CSFII 1994–1996 technical support files include the ingredient nutrient database and recipe data that USDA used to calculate the nutrient composition of survey foods from their ingredients (USDA, 1998). We assigned boron values to ingredients and then utilized the recipe data to calculate boron for many of the survey foods. A CSFII recipe was not used unless 100% of its ingredients had been assigned a boron value.

Ingredients. Boron concentrations were assigned to a total of 1267 ingredients, to be used for calculating the survey foods. Three hundred and fifteen ingredients were equivalent to analytical source foods and were assigned the same boron values; boron concentrations for 863 ingredients were calculated using proximate comparisons; and boron concentrations for 89 ingredients involved recipe calculations from two or more source foods.

Survey foods. From the analytical and ingredient data, boron concentrations were then assigned to a total of 4279 survey foods. Three hundred and forty foods were equivalent to analytical source foods and were assigned the same boron values; boron concentrations for 107 foods were calculated using proximate comparisons; and the CSFII recipe files were used to calculate boron concentrations for 3865 foods from the ingredient boron data. Although survey respondents did not consume many of these recipe foods, the boron values were obtained while processing the CSFII recipe data.

CSFII respondents consumed a total of 5682 foods. Of these, 3652 had boron concentrations in version 2.0 of the BNDB, representing 96% by weight of all foods consumed.

Continuing Survey of Food Intakes by Individuals (CSFII) 1994–1996

The CSFII 1994–1996 was conducted between January 1994 and January 1997 by the Agricultural Research Service (ARS) of the USDA. Two non-consecutive days of dietary data were collected for individuals of all ages through in-person interviews using 24-h recalls. The CSFII 1994–1996 data set comprises a nationally representative sample of noninstitutionalized persons residing in the 50 states of U.S.A. and Washington, DC. Further details on the survey design and methodology may be found in CSFII 1994–1996 reports and documentation (USDA, 1998).

Dietary Boron Intakes

Daily boron intakes were determined for each subject in the CSFII 1994–1996 who completed two days of dietary recall interviews (n = 15 267). This was done by linking version 2.0 of the BNDB with each respondent's individual food records (USDA, 1998). Adjusted distributions of usual boron intakes were then estimated for different age and sex groups, using C-SIDE software (Dodd, 1996) and implementing the statistical methods of Nusser *et al.* (1996). Usual intake represents the long-run average intake for an individual and is estimated by removing the individual's day-to-day variability in the measurement. Thus the adjusted intake distributions reflect only the person-to-person variation. The method was designed to address the different features of daily dietary intake data, including nuisance effects (such as day of the week and interview sequence), survey weights, nonnormality, measurement error, and heterogeneous variances. The steps involved preliminary data adjustments, semiparametric transformation to normality, estimation of within- and between-individual variances and back-transformation into the original scale. The adjusted distributions of usual boron intake were generated separately for each age and sex group. Standard errors for the various quantiles were estimated using the jackknife variance estimation option. These statistical methods are the same as those used to estimate dietary intakes of nutrients for the FNB's Standing Committee on the Scientific Evaluation of DRIs (FNB, 1998, 2000a, 2001). The age and sex groups are based on the FNB's life-stage groups for DRIs.

Major Contributors of Boron in the Diet

From the 1994–1996 CSFII individual food records, we obtained the weighted total grams of each survey food consumed by study participants 4 years and older, including pregnant and/or lactating females, who completed 2 days of dietary intake records. The data were weighted by applying the individual 3-year sample weights that were provided with the 1994–1996 CSFII data. The weighted sample is designed to represent the U.S. diet throughout the year. Using version 2.0 of the BNDB, we calculated the boron contribution from each food and its percent contribution to total boron. The foods were grouped into 154 individual food categories developed by Subar *et al.* (1998, 2000). For each food category we determined the percent contribution to total boron and the weighted, aggregate boron concentration. The categories were ranked by their percentage contribution to total dietary boron intake and cumulative percentages were calculated. The 50 food categories contributing the most boron in the diet were selected for reporting.

Daily Boron Intake by Food Group

To calculate boron intake by food group, we used the 11 major food groups developed by the USDA ARS for reporting food intakes from nationwide food consumption surveys. The major ARS groups are: total grain products; total vegetables; total fruits; total milk and milk products; total meat, poultry and fish; eggs; legumes; nuts and seeds; total fats and oils; total sugars and sweets; and total beverages. Mixtures are included in each group, categorized by the predominant ingredients. Details on the foods represented by these groups are contained in the CSFII 1994–1996 reports and documentation (USDA, 1998).

Eight of the age and sex categories were selected for reporting boron intake by food group: 4 years and older, 4–8 years, 14–18 years (male and female), 19–30 years (male and female), and 51–70 years (male and female). The 4 years and older category is the same population used for major contributors of boron in the diet, described above, and consists of all survey respondents age 4 and older (including pregnant and/or lactating females). For each age and sex category, we determined the weighted percent of boron contribution from each food group, in the same manner as described above for major contributors of boron in the diet. We applied the percentages of contribution to the adjusted mean daily boron intakes to determine mg boron per day from each food group.

RESULTS

Usual Intakes of Dietary Boron

Table 1 provides the mean, the 1st–99th percentiles and associated standard errors of usual boron intake for each age and sex category. The mean daily boron intake for all respondents age 4 and older was 1.07 $\pm$ 0.01 mg/d (S.E.), with 0.44 and 2.02 mg/d at the 5th and 95th percentiles. Intakes for school-age children and adolescents ranged from 0.80 $\pm$ 0.01 mg/d for 4–8 year olds to 1.02 $\pm$ 0.04 mg/d for 14–18-year-old males. The 5th and 95th percentiles for these groups were 0.43 and 1.29 mg/d for 4–8-year olds and 0.47 and 1.79 mg/d for 14–18-year-old males. Mean intakes for adults 19 years and older were 1.00 $\pm$ 0.01 mg/d for females and 1.28 $\pm$ 0.02 mg/d for males, with 5th and 95th percentiles of 0.41 and 1.87 mg/d for adult females and 0.53 and 2.40 mg/d for adult males. The lowest mean intakes for both female and male adults occurred in the 19–30 age group (0.87 $\pm$ 0.03 and 1.15 $\pm$ 0.03 mg/d, respectively) and the highest occurred in the 51–70 age group (1.11 $\pm$ 0.02 and 1.34 $\pm$ 0.02 mg/d, respectively). The mean usual boron intake was 1.16 $\pm$ 0.09 mg/d for pregnant females and 1.39 $\pm$ 0.16 mg/d for lactating females. These estimates for pregnant and lactating females are less reliable due to the smaller sample sizes (n = 70 and 41, respectively).

Major Contributors of Boron in the Diet

Table 2 lists the 50 major contributors of boron in the diet for persons 4 years and older (including pregnant and/or lactating females). Of 154 individual food categories, the top 50 represent 82.7% of total dietary boron intake in the 1994–1996 CSFII. Nearly one-third of the boron contributed by the top 50 foods is from foods consumed as beverages (32.1% of total boron). Six of the top 10 foods were consumed as beverages (coffee, wine, orange/grapefruit juice, milk, other juice, and soft drinks), contributing 28.4% of total boron. The boron content shown in Table 2 is the weighted, aggregate boron concentration of the foods consumed in each group. Among the top 50 boron contributors, the following are high in boron content: dried fruit (1870 µg/100g), avocado (1222 µg/100g), nuts and seeds (1214 µg/100g), nut/seed butters (1048 µg/100g), and wine (566 µg/100g).

Daily Boron Intake from Food Groups

Table 3 shows the distribution of daily boron intake from 11 food groups for eight selected age and sex categories. Fruit is the number one source of boron for the general population, comprising 25% of total boron intake for persons aged 4 and older and ranging from 20 to 40% for the other selected age and sex categories. The other food groups that significantly contribute to boron intake are the vegetable, grain, and beverage groups. In comparison to the individual food categories listed in

TABLE 1

Mean, percentiles, and associated standard errors (S.E.) for usual intake of boron (mg/d), based on CSFII 1994–1996 and the Boron Nutrient Database (version 2.0)[1–3]

Group/age[4,5]	n	Mean	Percentiles								
			1	5	10	25	50	75	90	95	99
		S.E.	S.E.	S.E.	S.E.	S.E.	S.E.	S.E.	S.E.	S.E.	S.E.
Children											
0–6 months	195	0.75	0.03	0.06	0.09	0.15	0.29	0.76	1.89	2.95	6.40
		0.14	0.01	0.01	0.01	0.01	0.05	0.15	0.44	0.63	1.99
7–11 months	130	0.99	0.12	0.20	0.27	0.42	0.71	1.21	2.00	2.70	4.77
		0.12	0.02	0.02	0.03	0.05	0.09	0.15	0.27	0.41	0.91
1–3 years	1834	0.86	0.25	0.35	0.42	0.57	0.78	1.07	1.41	1.66	2.24
		0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.04	0.05	0.08
4–8 years	1650	0.80	0.33	0.43	0.49	0.61	0.76	0.95	1.15	1.29	1.58
		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.04
Males											
9–13 years	552	0.90	0.38	0.49	0.56	0.69	0.86	1.07	1.28	1.43	1.74
		0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.05	0.06	0.09
14–18 years	446	1.02	0.34	0.47	0.55	0.72	0.96	1.25	1.57	1.79	2.28
		0.04	0.03	0.02	0.02	0.03	0.03	0.05	0.07	0.09	0.14
19–30 years	853	1.15	0.37	0.51	0.61	0.80	1.06	1.40	1.79	2.05	2.66
		0.03	0.02	0.02	0.02	0.02	0.03	0.04	0.06	0.08	0.12
31–50 years	1684	1.33	0.42	0.58	0.69	0.91	1.22	1.63	2.09	2.42	3.18
		0.03	0.02	0.02	0.02	0.02	0.02	0.04	0.06	0.09	0.15
51–70 years	1606	1.34	0.39	0.56	0.67	0.89	1.22	1.66	2.16	2.52	3.34
		0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.06	0.08	0.13
71+ years	674	1.25	0.31	0.46	0.56	0.78	1.11	1.56	2.12	2.53	3.51
		0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.07	0.10	0.20
Adult (19+ years)	4817	1.28	0.37	0.53	0.64	0.85	1.17	1.58	2.06	2.40	3.18
		0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.04	0.05	0.08
Females											
9–13 years	560	0.83	0.34	0.44	0.50	0.62	0.79	0.99	1.21	1.35	1.68
		0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.05	0.06	0.09
14–18 years	436	0.78	0.26	0.36	0.42	0.55	0.73	0.96	1.22	1.40	1.80
		0.04	0.02	0.02	0.02	0.02	0.03	0.05	0.07	0.08	0.13
19–30 years	760	0.87	0.30	0.40	0.48	0.62	0.81	1.06	1.34	1.54	1.97
		0.03	0.02	0.02	0.02	0.02	0.03	0.04	0.06	0.08	0.13

TABLE 1 (Continued).

Group/age[4,5]	*n*	Mean	Percentiles								
			1	5	10	25	50	75	90	95	99
		S.E.	S.E.	S.E.	S.E.	S.E.	S.E.	S.E.	S.E.	S.E.	S.E.
31–50 years	1614	1.00	0.31	0.44	0.52	0.69	0.93	1.23	1.58	1.83	2.39
		0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.04	0.07
51–70 years	1539	1.11	0.32	0.46	0.55	0.73	1.01	1.38	1.81	2.13	2.87
		0.02	0.01	0.01	0.01	0.01	0.02	0.03	0.05	0.07	0.12
71+ years	623	0.98	0.27	0.39	0.47	0.64	0.89	1.21	1.59	1.86	2.47
		0.03	0.02	0.02	0.02	0.02	0.03	0.04	0.06	0.09	0.15
Adult (19+ y)	4536	1.00	0.29	0.41	0.50	0.67	0.92	1.24	1.61	1.87	2.47
		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.05
Pregnant (P)	70	1.16	0.37	0.52	0.62	0.81	1.08	1.42	1.79	2.06	2.64
		0.09	0.06	0.07	0.07	0.08	0.09	0.11	0.16	0.20	0.33
Lactating (L)	41	1.39	0.38	0.55	0.67	0.92	1.27	1.73	2.26	2.64	3.49
		0.16	0.10	0.12	0.13	0.14	0.15	0.20	0.31	0.43	0.75
All persons	15156	1.06	0.28	0.41	0.50	0.68	0.96	1.32	1.75	2.07	2.79
		0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.05
All+P/L	15267	1.06	0.28	0.41	0.50	0.68	0.95	1.32	1.75	2.06	2.79
		0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.05
All 4+*years*	12997	1.07	0.31	0.44	0.53	0.71	0.97	1.32	1.72	2.01	2.68
		0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.04
All 4+*years*+*P/L*	13108	1.07	0.31	0.44	0.53	0.71	0.97	1.32	1.73	2.02	2.68
		0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.03	0.04

[1]U.S. Department of Agriculture Continuing Survey of Food Intakes by Individuals (CSFII), 1994–1996, 2 days (USDA, 1998).

[2]Estimates were obtained using C-SIDE v1.02, courtesy of Iowa State University Statistical Laboratory. *n* represents the actual unweighted sample size in each group. Standard errors were estimated via jackknife replication. Each standard error has 43 degrees of freedom (Dodd, 1996; Nusser *et al*., 1996).

[3]Boron Nutrient Database (version 2.0) developed by the authors in this study.

[4]Does not include pregnant/lactating females unless indicated.

[5]Does not include boron from breast milk.

TABLE 2

Fifty major contributors of boron in the diet, based on CSFII 1994–1996[1] and the Boron Nutrient Database (version 2.0)[2]

Rank	Food category[3]	Percent of total boron consumed	Cumulative percent of boron	Boron content[4] (μg/100 g)
1	Coffee	8.6	8.6	34
2	Wine	5.1	13.7	566
3	Orange/grapefruit juice	4.4	18.1	79
4	Milk	4.2	22.3	23
5	Other juice	4.0	26.3	202
6	Apples	3.6	29.9	273
7	Beans	3.2	33.1	216
8	Fried potatoes	2.7	35.8	147
9	Soft drinks/soda	2.1	37.9	6
10	Bananas	2.1	39.9	137
11	Peaches/nectarines/plums	2.0	41.9	352
12	Potatoes, not fried	1.9	43.8	62
13	Soup	1.8	45.6	44
14	Nut/seed butters	1.8	47.3	1048
15	Nuts/seeds, whole	1.7	49.1	1214
16	Potato/corn/other chips	1.5	50.6	206
17	Pasta	1.5	52.2	44
18	Grapes	1.5	53.7	460
19	Pizza	1.5	55.2	83
20	Ready-to-eat cereal	1.5	56.7	128
21	Fruit drinks	1.5	58.2	18
22	Tea	1.5	59.6	11
23	Oranges, tangelos, etc.	1.4	61.1	215
24	Breads	1.4	62.5	33
25	Dried fruit	1.2	63.6	1870
26	Tomato sauce	1.1	64.7	132
27	Rice/grains	1.1	65.8	34
28	Lettuce	1.0	66.8	70
29	Other vegetables	1.0	67.8	119
30	Chili	1.0	68.8	136
31	Tomatoes	0.9	69.7	76
32	Mexican mixtures	0.9	70.7	93
33	Beef stews/pot pies/mixtures	0.9	71.6	55
34	Broccoli	0.9	72.4	165
35	Chicken mixtures	0.8	73.3	48
36	Fruit salads/other fruits	0.8	74.1	183
37	Carrots	0.7	74.8	141
38	Avocado, guacamole	0.7	75.6	1222
39	Applesauce/cooked apples	0.7	76.3	219
40	String beans	0.7	77.0	107
41	Beer	0.7	77.7	8
42	Cakes	0.7	78.3	100
43	Fish, not fried	0.6	78.9	74
44	Pears	0.6	79.5	204
45	Other melons	0.6	80.1	70
46	Cookies, brownies	0.6	80.6	112
47	Beef, burgers	0.5	81.2	23
48	Onions	0.5	81.7	168
49	Donuts, sweet rolls, etc.	0.5	82.2	69
50	Corn	0.5	82.7	57

[1]U.S. Department of Agriculture Continuing Survey of Food Intakes by Individuals (CSFII), 1994–1996 (weighted, 2 days, age 4 and older) (USDA, 1998).
[2]Boron Nutrient Database (version 2.0) developed by the authors in this study.
[3]Foods were grouped into 154 categories according to similarities in nutrient content or use (Subar *et al.*, 1998, 2000).
[4]Weighted, aggregate boron concentration of foods within the category.

TABLE 3

Daily boron intake by food group, based on CSFII 1994–1996[1] and the Boron Nutrient Database (version 2.0)[2]

Food Group[3]	Milligrams per day/percent of total boron							
	4+ years	4–8 years	14–18 years		19–30 years		51–70 years	
			Male	Female[4]	Male	Female[4]	Male	Female[4]
Grains	0.151	0.122	0.216	0.147	0.202	0.138	0.153	0.111
	14.1%	15.3%	21.2%	18.8%	17.7%	15.8%	11.4%	10.0%
Vegetables	0.194	0.105	0.206	0.143	0.230	0.174	0.237	0.202
	18.1%	13.2%	20.2%	18.2%	20.1%	19.9%	17.7%	18.1%
Fruits	0.269	0.317	0.225	0.252	0.224	0.192	0.322	0.310
	25.1%	39.8%	22.0%	32.2%	19.6%	22.1%	24.0%	27.8%
Milk/milk products	0.062	0.091	0.100	0.055	0.057	0.048	0.054	0.049
	5.8%	11.5%	9.8%	7.0%	5.0%	5.5%	4.0%	4.4%
Meat/poultry/fish	0.078	0.042	0.084	0.070	0.106	0.067	0.093	0.067
	7.3%	5.2%	8.2%	8.9%	9.2%	7.6%	6.9%	6.0%
Eggs	0.003	0.002	0.004	0.002	0.006	0.003	0.005	0.003
	0.3%	0.3%	0.4%	0.3%	0.5%	0.3%	0.4%	0.3%
Legumes	0.046	0.021	0.035	0.029	0.060	0.039	0.067	0.039
	4.4%	2.6%	3.5%	3.7%	5.3%	4.4%	5.0%	3.5%
Nuts/seeds	0.038	0.045	0.038	0.014	0.051	0.022	0.062	0.026
	3.5%	5.7%	3.7%	1.8%	4.5%	2.5%	4.6%	2.3%
Fats/oils	0.004	0.001	0.003	0.002	0.004	0.004	0.004	0.004
	0.3%	0.2%	0.3%	0.3%	0.3%	0.5%	0.3%	0.4%
Sugars/sweets	0.016	0.016	0.022	0.015	0.014	0.016	0.020	0.015
	1.5%	2.0%	2.1%	1.9%	1.2%	1.9%	1.5%	1.4%
Beverages	0.208	0.033	0.089	0.056	0.191	0.169	0.324	0.288
	19.5%	4.2%	8.7%	7.2%	16.7%	19.4%	24.2%	25.8%
Total boron	1.068	0.796	1.022	0.785	1.145	0.872	1.340	1.114

[1]U.S. Department of Agriculture Continuing Survey of Food Intakes by Individuals (CSFII), 1994–1996 (weighted, 2 days) (USDA, 1998).
[2]Boron Nutrient Database (version 2.0) developed by the authors in this study.
[3]Foods grouped according to USDA, ARS documentation on calculated variables (USDA, 1998).
[4]Does not include pregnant/lactating females.

Table 2, it should be noted that the beverage food group in Table 3 does not include milk (which is in the milk/milk products group) or fruit juices (which are in the fruit group).

DISCUSSION

This study provides current data on the usual boron intakes of apparently healthy individuals. We believe that these data are the most accurate estimates of dietary boron intake because the BNDB has been updated to be more inclusive and accurate and because we used a statistical approach that was designed to estimate usual intake based on a limited number of days of consumption data. These mean estimates of usual boron intake for the CSFII 1994–1996 (1.00 mg/d for adult females and 1.28 mg/d for adult males) fall within the range of previously reported mean estimates. They are slightly higher than some, such as our earlier CSFII 1989–1991 study (0.96 and 1.17 mg/d for adult females and males, respectively) (Rainey *et al.*, 1999b) and one study of FDA Total Diet Study foods (0.93 and 1.21 mg/d for 25–30-year-old females and males, respectively) (Anderson *et al.*, 1994). However, they are slightly lower than the mean of two other Total Diet Studies (1.52 mg/d for 25–30-year-old males) (Iyengar *et al.*, 1990) and the mean of 1-day diet composites from 22 pre-menopausal Canadian women (1.33 mg) (Clarke and Gibson, 1988). These differences may be partially due to differences in survey techniques or methods used to summarize the data.

Our earlier comparison of boron intake from six different countries (U.S., Germany, Great Britain, Mexico, Kenya, and Egypt) showed that the boron intake in the U.S. was the lowest (Rainey *et al.*, 1999a). The current study's estimates for boron intake in the U.S. are also lower than those for the other countries examined. This is presumably due to a lower intake of fruits, vegetables, and legumes in the U.S. compared to others. However, *The Healthy Eating Index: 1994–96* reported an increase in servings of fruit, vegetables/legumes and grains from 1989 to 1996 (Bowman *et al.*, 1998), and USDA reports from the CSFII 1994–1996 and CSFII 1989–1991 confirm increased gram consumption of these food groups (Tippett *et al.*, 1995; USDA, 1998). Despite the increases, boron intake in the U.S. still remains below that of other countries studied. The biological effects of humans having higher or lower boron intakes are not yet clearly defined; however, human clinical experiments have been conducted in which subjects responded to boron supplementation after consuming a low boron diet (Nielsen, 1996; Hunt *et al.*, 1997). This suggests that there are low intakes of boron that can be increased with beneficial results.

It should be noted that the CSFII 1994–1996 and our boron intake estimates did not include drinking water, which can be a major source of boron depending on the local boron concentration (Coughlin, 1998). Data for many cooked foods and prepared beverages, however, did include the boron contribution from the water used to prepare them. In addition, there are many possible sources of error in carrying out this type of data analysis that should be mentioned. These include: zero boron values in the database, use of imputed boron values, the many errors inherent in collecting dietary information from individuals, and variations in boron content of soils that can significantly change the boron content of foods. These biases were not taken into consideration in the present study because there were no quantitative estimates of these effects when our analyses were conducted. Despite the possible sources of error and with the information currently available, these data represent the best estimates that we are able to make at this time.

CONCLUSIONS

The data obtained in this study provide the most up-to-date estimates of usual dietary boron intake in a healthy population, which will be useful in the future development of recommended intake levels for boron. As data become available on boron requirements for humans, these estimates may be used to assess whether Americans are receiving adequate daily boron. The estimates could be further improved if more analytical data were available on the boron concentrations of U.S. foods, and we urge that further boron analyses be conducted by commodity growers, food and beverage processors, and academic and government laboratories.

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REFERENCES

Al-Warthan, A. A., Al-Showman, S. S., Al-Tamrah, S. A., and BaOsman, A. A. (1993). Spectrophotometric determination of boron in dates of some cultivars grown in Saudi Arabia. *J. AOAC Int*. **76**(3), 601–603.

Anderson, D. L., Cunningham, W. C., and Lindstrom, T. R. (1994). Concentrations and intakes of H, B, S, K, Na, Cl and NaCl in foods. *J. Food Comp. Anal*. **7,** 59–82.

Bionda, G. (1957) Contrôle de la teneur en bore des vins naturels de la province de Pavie, Italie (Control of the quantity of boron in the natural wines of the province of Pavie, Italy). *Ann. Falsif. Fraudes*. **50,** 15–23.

Bowman, S. A., Lino, M., Gerrior, S. A., and Basiotis, P. P. (1998). *The Healthy Eating Index: 1994–96*. CNPP-5. U.S. Department of Agriculture, Center for Nutrition Policy and Promotion, Washington, DC.

Clarke, W. B. and Gibson, R. (1988). Lithium, boron, and nitrogen in 1-day composites and a mixed-diet standard. *J. Food Comp. Anal*. **1,** 209–220.

Clarke, W. B., Koekebakker, M., Barr, R. D., Downing, R. G., and Fleming, R. F. (1987). Analysis of ultratrace lithium and boron by neutron activation and mass-spectrometric measurement of 3He and 4He. *Appl. Radiat. Isot*. **38,** 735–743.

Coughlin, J. R. (1998). Sources of human exposure: overview of water supplies as sources of boron. *Biol. Trace Elem. Res*. **66,** 87–100.

Dodd, K. W. (1996). *A Technical Guide to* C-SIDE, *Software for Intake Distribution Estimation*. Technical Report 96-TR 32, Dietary Assessment Research Series Report 9, September 1996. Department of Statistics and Center for Agricultural and Rural Development (CARD), Iowa State University, Ames, IA.

Eckhert, C. D. and Rowe, R. I. (1999). Embryonic dysplasia and adult retinal dystrophy in boron-deficient zebrafish. *J. Trace Elem. Exp. Med*. **12,** 213–219.

FNB (Food and Nutrition Board, Institute of Medicine) (1998). *Dietary Reference Intakes for Thiamin, Riboflavin, Niacin, Vitamin B6, Folate, Vitamin B12, Pantothenic Acid, Biotin, and Choline*. National Academy Press, Washington, DC.

FNB (Food and Nutrition Board, Institute of Medicine) (2000a). *Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium, and Carotenoids*. National Academy Press, Washington, DC.

FNB (Food and Nutrition Board, Institute of Medicine) (2000b). *Micronutrients*. Retrieved March 9, 2000 from the World Wide Web: http://www4.nas.edu/IOM/IOMHome.nsf/Pages/FNB+Micronutrients.

FNB (Food and Nutrition Board, Institute of Medicine) (2001). *Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc*. National Academy Press, Washington, DC.

Fort, D. J., Stover, E. L., Strong, P. L., Murray, F. J., and Keen, C. L. (1999). Chronic feeding of a low boron diet adversely affects reproduction and development in *Xenopus laevis*. *J. Nutr*. **129,** 2055–2060.

Haytowitz, D. (1989). *USDA's Nutrient Data Bank—A National Resource*. Paper presented at American Association of Cereal Chemists 74th Annual Meeting, October 31, 1989, Washington, DC.

Holden, J. M., Schubert, A., Wolf, W. R., and Beecher, G. R. (1987). A system for evaluating the quality of published nutrient data: selenium, a test case. *Food Nutr. Bull.* **9** (SUPPL.), 177–193.

Hunt, C. D. (1996). Biochemical effects of physiological amounts of dietary boron. *J. Trace Elem. Exp. Med.* **9,** 185–213.

Hunt, C. D., Herbel, J. L., and Nielsen, F. H. (1997). Metabolic responses of postmenopausal women to supplemental dietary boron and aluminum during usual and low magnesium intake: boron, calcium, and magnesium absorption and retention and blood mineral concentrations. *Am. J. Clin. Nutr.* **65,** 803–813.

Hunt, C. D. and Meacham, S. L. (2001). Aluminum, boron, calcium, copper, iron, magnesium, manganese, molybdenum, phosphorus, potassium, sodium, and zinc: concentrations in common western foods and estimated daily intakes by infants; toddlers; and male and female adolescents, adults, and seniors in the United States. *J. Am. Diet. Assoc.* **101,** 1058–1060.

Hunt, C. D., Shuler, T. R., and Mullen, L. M. (1991). Concentration of boron and other elements in human foods and personal care products. *J. Am. Diet. Assoc.* **91,** 558–568.

Hunt, C. D. and Stoecker, B. J. (1996). Deliberations and evaluations of the approaches, endpoints and paradigms for boron, chromium and fluoride dietary recommendations. *J. Nutr.* **126** (Suppl.), 2441S–2451S.

Inoue, T., Iwaida, M., Ito, Y., Gawa, S., Tajima, K., Mine, T., Fukabawa, Y., and Kubota, S. (1980). A general survey on borate contents in foods. *J. Food Hyg. Soc.* **21,** 465–481.

Iyengar, G. V., Clarke, W. B., and Downing, R. G. (1990). Determination of boron and lithium in diverse biological matrices using neutron activation-mass spectrometry (NA-MS). *Fresenius J. Anal. Chem.* **338,** 562–566.

Lu, G., Li, X., and Deng, Y. (1994). Polarographic determination of trace boron in foods. *Food Chem.* **50,** 91–93.

Lurie, D. G., Holden, J. M., Schubert, A., Wolf, W. R., and Miller-Ilhi, N. J. (1989). The copper content of foods based on a critical evaluation of published analytical data. *J. Food Comp. Anal.* **2,** 298–316.

Mangels, A. R., Holden, J. M., Beecher, G. R., Forman, M. R., and Lanza, E. (1993). Carotenoid content of fruits and vegetables: an evaluation of analytic data. *J. Am. Diet. Assoc.* **93,** 284–296.

MAFF (Ministry of Agriculture, Fisheries and Food) (1998a). *Concentrations of Metals and Other Elements in Selected Snack and Convenience Foods.* Food Surveillance Information Sheet No. 146, March 1998. Retrieved December 1998 from the World Wide Web: http://www.maff.gov.uk.

MAFF (Ministry of Agriculture, Fisheries and Food) (1998b). *Concentrations of Metals and Other Elements in Marine Fish and Shellfish.* Food Surveillance Information Sheet No. 151, May 1998. Retrieved December 1998 from the World Wide Web: http://www.maff.gov.uk.

Minoia, C., Sabbioni, E., Ronchi, A., Gatti, A., Pietra, R., Nicolotti, A., Fortaner, S., Balducci, C., Fonte, A., and Roggi, C. (1994). Trace element reference values in tissues from inhabitants of the European Community: IV. Influence of dietary factors. *Sci. Total Environ.* **4,** 181–195.

Murphy, S. P., Weinberg-Andersson, S. W., Neumann, C., Mulligan, K., and Calloway, D.H. (1991). Development of research nutrient databases: an example using foods consumed in rural Kenya. *J. Food Comp. Anal.* **4,** 2–17.

Nielsen, F. H. (1996). Evidence for the nutritional essentiality of boron. *J. Trace Elem. Exp. Med.* **9,** 215–229.

Nusser, S. M., Carriquiry, A. L., Dodd, K. W., and Fuller, W. A. (1996). A semi-parametric transformation approach to estimating usual daily intake distributions. *J. Am. Stat. Assoc.* **91,** 1440–1449.

Nuurtamo, M., Varo, P., Saari, E., and Koivistoinen, P. (1980a). Mineral element composition of Finnish foods: V. Meat and meat products. *Acta Agric. Scand.* **22** (Suppl.), 58–76.

Nuurtamo, M., Varo, P., Saari, E., and Koivistoinen, P. (1980b). Mineral element composition of Finnish foods: VI. Fish and fish products. *Acta Agric. Scand.* **22** (Suppl.), 78–87.

Ogawa, S., Toyoda, M., Tonogal, Y., Ito, Y., and Iwaida, M. (1979). Colorimetric determination of boric acid in prawns, shrimp, and salted jelly fish by chelate extraction with 2-ethyl-1,3-hexanediol. *J. Assoc. Off. Anal. Chem.* **62,** 610–614.

Perloff, B. P., Rizek, R. L., Haytowitz, D. B., and Reid, P. R. (1990). Dietary intake methodology II. USDA's Nutrient Data Base for Nationwide Dietary Intake Surveys. *J. Nutr.* **120,** 1530–1534.

Rainey, C., Nyquist, L., Casterline, J., and Herman, D. (1999a). Estimation of dietary boron intake in six countries: Egypt, Germany, Great Britain, Kenya, Mexico and the United States. *J. Trace Elem. Exp. Med.* **12,** 263–270.

Rainey, C. J., Nyquist, L. A., Christensen, R. E., Strong, P. L., Culver, B. D., and Coughlin, J. R. (1999b). Daily boron intake from the American diet. *J. Am. Diet. Assoc.* **99,** 335–340.

Rand, W. M., Pennington, J. A. T., Murphy, S. P., and Klensin, J. C. (1991). *Compiling Data for Food Composition Databases.* United Nations University, Tokyo, Japan.

Rowe, R. I., Bouzan, C., Nabili, S., and Eckhert, C. D. (1998). The response of trout and zebrafish embryos to low and high boron concentrations is U-shaped. *Biol. Trace Element Res.* **66,** 261–270.

Schubert, A., Holden, J. M., and Wolf, W. R. (1987). Selenium content of a core group of foods based on a critical evaluation of published analytical data. *J. Am. Diet. Assoc.* **87,** 285–296, 299.

Souci, S. W., Fachmann, W., and Kraut, H. (1994). *Food Composition and Nutrition Tables,* pp. 955–956. Wissenschaftlich Verlagsgesellschaft, Stuttgart, Germany.

Subar, A. F., Krebs-Smith, S. M., Cook, A., and Kahle, L. L. (1998). Dietary sources of nutrients among U.S. adults, 1989 to 1991. *J. Am. Diet. Assoc.* **98,** 537–547.

Subar, A. F., Midthune, D., Kulldorff, M., Brown, C. C., Thompson, F. E., Kipnis, V., and Schatzkin, A. (2000). An evaluation of alternative approaches to assigning nutrient values to food groups in food frequency questionnaires. *Am. J. Epidemiol.* **152,** 279–286.

Tippett, S., Mickle, S. J., Goldman, J. D., Sykes, K. E., Cook, D. A., Sebastian, R. S., Wilson, J. W., and Smith, J. (1995). *Food and Nutrient Intakes by Individuals in the United States, 1 Day, 1989–91.* Continuing Survey of Food Intakes by Individuals, 1989–1991, Nationwide Food Surveys Report No. 91-2. U.S. Department of Agriculture, Agricultural Research Service, Beltsville, MD.

USDA (U.S. Department of Agriculture, Agricultural Research Service) (1998). *1994–96 Continuing Survey of Food Intakes by Individuals and 1994–96 Health Knowledge Survey, (CSFII/CHKS).* CD-ROM. Available from National Technical Information Service, Springfield, VA.

USDA (U.S. Department of Agriculture, Agricultural Research Service) (1999). *USDA Nutrient Database for Standard Reference, Release 12.* CD-ROM. Beltsville Human Nutrition Research Center, Nutrient Data Laboratory, Riverdale, MD.

Varo, P., Lahelma, O., Nuurtamo, M., Saari, E., and Koivistoinen, P. (1980a). Mineral element composition of Finnish foods: VII. Potato, vegetables, fruits, berries, nuts, and mushrooms. *Acta Agric. Scand.* **22** (Suppl.), 90–113.

Varo, P., Nuurtamo, M., Saari, E., and Koivistoinen, P. (1980b). Mineral element composition of Finnish foods: IV. Flours and bakery products. *Acta Agric. Scand.* **22** (Suppl.), 38–55.

Varo, P., Nuurtamo, M., Saari, E., and Koivistoinen, P. (1980c). Mineral element composition of Finnish foods: VIII. Dairy products, eggs and margarine. *Acta Agric. Scand.* **22** (Suppl.), 115–126.

Varo, P., Nuurtamo, M., Saari, E., and Koivistoinen, P. (1980d). Mineral element composition of Finnish foods: IX. Beverages, confections, sugar, and condiments. *Acta Agric. Scand.* **22** (Suppl.), 128–139.

WHO (World Health Organization) (1996). Boron. Chapter 13. In: *Trace Elements in Human Nutrition and Health.* Report of the Joint FAO/IAEA/WHO Expert Consultation on Trace Elements in Human Nutrition, pp. 175–179. World Health Organization, Geneva, Switzerland.